CONFIDENTIAL

Technical Brief

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Panel Mounted Surge Suppressor EMI/RFI Filters And Sine Wave Tracking

1. Introduction

Since the early 1980s, the FCC in the United Stated and the VDE in Germany imposed mandatory standards and testing for electromagnetic **emissions**. Later, the countries of the European Union imposed mandatory requirements for electromagnetic **immunity**. Today, because electrical and electronic systems manufacturers operate on a global basis, a number of mandatory standards regulating electromagnetic emission and electromagnetic immunity must be met.

Equipment levels of EMI (electromagnetic interference) and RFI (radio-frequency interference) both for emissions and immunity are regulated. Power line conducted EMI/RFI, the EMI/RFI, which is injected onto the power lines by an electrical device, is regulated. This prevents the "pollution" of the local electrical distribution system and prevents the possible "jamming" of one device by another on the same distribution circuit. Electronic systems (e.g., computers, TV sets, medical equipment, etc.) have which low conducted EMI/RFI emissions also have high EMI/RFI immunity because the filters work in both directions. That is, they limit both the outgoing and incoming EMI/RFI pollution.

EMI/RFI power line filters address low amplitude conducted EMI/RFI and are designed into modern electronic systems to meet international requirements. This conducted EMI/RFI (not to be confused with high amplitude, low frequency power line harmonics) typically ranges from the kilohertz to megahertz frequency range. Thus, the frequency of the conducted EMI/RFI is thousands to millions of times higher than the 60 hertz power frequency. Typical amplitudes for the conducted EMI/RFI lie in the microvolt (millionths of a volt) to the millivolt (thousandths of a volt) range, as opposed to a peak voltage of 170 volts on a 120 volt rms, 60 hertz power distribution circuit. Consider a one hundred millivolt (0.100 volts) EMI/RFI voltage level riding on a 170 volt peak (120 Volts rms), 60 hertz sine wave. On an oscilloscope, the conducted EMI/RFI looks like "fuzz" riding on the 60 hertz power frequency sine wave. The peak value of this sine wave is 1,700 times the amplitude of the 0.100 volt EMI/RFI (170 volts/0.100 volts = 1,700). At the zero crossing of the ac power sine wave, the worst case EMI/RFI amplitude will be 0.100 volts against an instantaneous ac voltage of zero volts. Will this 0.100 volt EMI/RFI pass through the input EMI/RFI filter of an analog or switch mode power supply, through the power supply output filter and on to the dc busses powering the integrated circuit electronics? No. Will this conducted EMI/RFI disrupt, damage, or destroy sensitive electronic systems? No. When it comes to selling panel mounted surge suppressors, EMI/RFI specifications for these panel mounted surge suppressors should be considered a sales gimmick. This is a "solution" in search of a "problem."

NEMA LS-1 encouraged the presentation of this data, so the industry fell in line. The panel mounted surge suppressor EMI/RFI specifications provided to engineers and consumers are not meaningful or accurate. This will be discussed in sections that follow.

A sine wave tracking panel mounted surge suppressor solve real problems, with real transients that can disrupt, damage, and destroy sensitive electronic systems. This will be discussed below.

EMI/RFI filters and sine wave tracking are not the same thing. This will be discussed below.

2. EMI/RFI filters for panel mounted surge suppressors.

Panel mounted surge suppressors are typically connected in parallel to the electrical distribution system so that that the load current does not pass through the surge suppressor. For EMI/RFI filtration by-pass capacitors are generally connected in the phase-to-neutral modes. These capacitors are in parallel with the respective phase-to-line modes. There are four main issues concerning TVSS EMI/RFI noise attenuation specifications:

A. The measurement or calculation method(s) employed to obtain the sales data.
B. The assumptions of the measurement technique or calculation methods.
C. The actual installed performance versus stated sales data.
D. The actual impact upon power quality and equipment operation.

2.A. The measurement or calculation method(s) employed to obtain the sales data.

The standard filter attenuation measurement method is known as the 50 ohm insertion loss method. This methodology was embodied in MIL-STD-220A, and stems from the convention used by radio engineers before World War II. This method uses a variable frequency oscillator with an internal impedance of 50 ohms resistive and a 50 ohm resistive load placed on the output of the filter under test. This works well for radio frequency circuits, but creates useless data for ac power distribution systems.

2.B. The assumptions of the measurement technique or calculation methods.

For ac power distribution systems, from dc to a few kilohertz, the common mode and differential mode impedance of the ac power mains are roughly equivalent to their dc resistance (for solidly grounded neutral systems). This is sometimes expressed as short circuit ampacity, and is almost always less than one ohm. For example, a large high-voltage building service entrance may have a mains impedance of 0.003 ohms to 0.010 ohms and a large commercial/industrial room panel (100 kVa) may have a mains impedance of 0.020 ohms. The net effect of the actual mains impedance being much, much less than the 50 ohms used in the MIL-STD-220A test is that the actual attenuation of a panel connected surge suppressor with EMI/RFI filter capacitors will also be much, much less. For example, an ideal (no lead length or circuit wiring inductance) 0.63 microfarad by-pass capacitor tested with a 50 ohm resistive impedance oscillator and with a 50 ohm resistive load, will produce an attenuation of roughly 40 decibles at a frequency of 1 MHz. The same ideal capacitor tested with a 0.060 ohm resistive internal impedance oscillator and a

load impedance of 2 ohms resistive will produce an attenuation of 0 decibles at 1 Mhz and only about 8 decibels at 10 MHz. Clearly, when actual ac power distribution system impedances, load impedances, and circuit inductance are considered, EMI/RFI attenuation data based upon the 50 ohm insertion loss method are meaningless.

2.C. The actual installed performance versus stated sales data.

To further illustrate the absurdity of applying the 50 ohm insertion loss method to these types of filters and to realize that "promise" of a Mil-Std-200A filter response on a power distribution system, the power distribution mains impedance would have to be 50 ohms resistive and the load would have to be 50 ohms resistive. Consider a 1,000 amp. circuit with a mains impedance of 50 ohms. The power dissipation at the mains under a 1,000 amp. load would be $P = i^2 \times r$ (current squared times resistance):

$$P = i^2 \times r = (1,000 \text{ amps.}) \times (1,000 \text{ amps.}) \times (50 \text{ ohms})$$
$$P = \textbf{50,000,000 watts!}$$

This would melt the down the service entrance equipment, unless we used water-cooled busses or devised some other scheme to dissipate the heat.

Consider a perfectly efficient electric motor. This 50,000,000 watts is equivalent to (1 horsepower = 745.7 watts) a 67,051 horsepower electrical motor. This is not realistic.

Or, suppose a residence or small business is drawing 100 amperes at 120 volts, the power dissipation is:

$$P = i \times e = (100 \text{ amps}) \times (120 \text{ volts}) = 12,000 \text{ watts per residence or small business}$$

Now, 50,000,000 watts divided by 12,000 watts per residence = (50,000,000 / 12,000 = 4,166 residences) 4,166 residences. This is not realistic either.

2.D. The actual impact upon power quality and equipment operation.

To properly design and apply an EMI/RFI filter you must know what you are filtering (e.g., the frequency spectrum and amplitude of the offending signal), the mode(s) you wish to filter, and the input and output impedances so that you can properly match the filter to the circuit and allow the filter to operate properly.

Clearly, the 50 ohm insertion loss method is absurd when applied to power distribution systems. Unfortunately, most people are not aware that this methodology is meaningless when so applied. It has become a "gee-whiz" number on product specification sheets that most manufacturers have been forced to adopt due to the competitive environment. As discussed above, given the magnitudes and frequencies of conducted EMI/RFI, the mandatory standards developed and implemented over the last 20 years, the method of filter attenuation measurement, the lack of correspondence between the measurement methods and actual ac power distribution systems, it

is reasonable to state that this is a "solution" in search of a "problem." And, the impact upon equipment operation and power quality can be expected to be nil.

3. Sine wave tracking panel mounted surge suppressors.

3.A. Introduction.

There are two basic types of panel mounted transient voltage surge suppressors (TVSS) or surge protection device (SPD) protection circuitry designs. The first type is known as threshold clamping or fixed clamping device circuitry. A threshold clamping TVSS provides circuitry which yields a fixed clamping level above the positive peak of the power frequency voltage sine wave and below the negative peak of the power frequency voltage sine wave for a given transient wave shape and amplitude. The fixed clamping level is set by the TVSS designer to allow sufficient "headroom" above the positive and negative peaks of the power frequency sine wave to ensure that the TVSS will tolerate normal power frequency voltage fluctuations without interacting with the applied system voltage. Threshold clamping circuitry is passive until a voltage transient reaches the designed preset clamping voltage level in either the positive or negative direction (polarity). When the voltage transient reaches the preset level, the threshold clamping TVSS becomes active, begins to turn on and begins to suppress the voltage transient.

A TVSS with sine wave tracking circuitry is designed to immediately address ring wave voltage transients (and other short duration, fast rise time transients) as they leave the power frequency sine wave. The sine wave tracking circuitry does not require "headroom" above the positive or negative peaks of the applied power frequency voltage sine wave and does not interact with the applied power frequency voltage.

3.B. Threshold or Fixed Clamping TVSS Circuitry.

As stated above, the threshold or fixed clamping TVSS circuitry has a preset voltage level at which it becomes active. This preset voltage level must provide adequate headroom for normal supply voltage operating swings. A positive or negative going transient must reach the preset or fixed clamping voltage level before the TVSS acts upon it. A pictorial representation of transients reaching this preset clamping voltages is shown in Figure 1. below. A 60 Hertz, 120 volt rms or 170 volt peak sine wave is shown with positive and negative transients, represented by the arrows, reaching the preset or fixed voltage levels.

Figure 1. 60 Hz, 120 V rms sine wave with preset voltage levels with positive and negative transients.
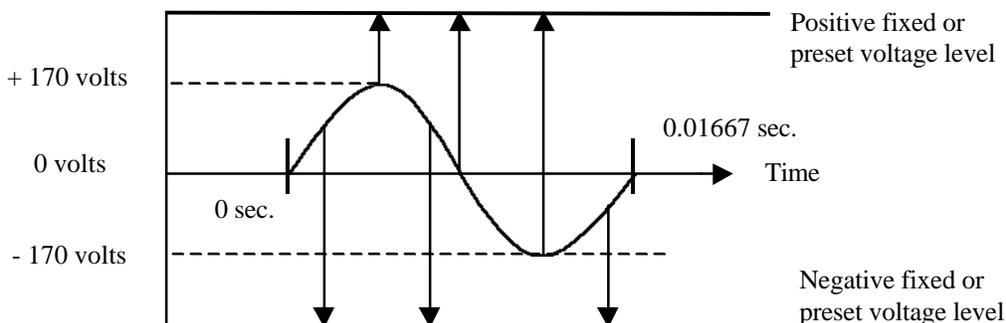
The positive and negative fixed or preset voltage levels are symmetrical about the zero voltage level. The TVSS is passive (inactive) until the transients (represented by arrows) reach the positive or negative fixed preset voltage levels. Note that these preset voltage levels must accommodate normal system voltage swings.

3.C. Sine Wave Tracking TVSS Circuitry.

Sine wave tracking circuitry is capable of addressing ring wave transients and other short duration, fast rise time transients immediately as they leave the power frequency sine wave without interaction with the applied power frequency voltage sine wave. Headroom is not required for sine wave tracking circuitry to operate.

The ring wave transients are a natural result of the distributed inductance, capacitance, and resistance of power distribution circuits. A mechanical analogy of electrical ring wave transients is mechanical resonance. For example, when a guitar string is plucked the sting resonates and produces a tone. The amplitude (or volume of the tone) decays or becomes fainter over time until it becomes inaudible. When an electrical distribution system is similarly disturbed, it too resonates or rings and the amplitude of the ring wave decays. The standard characterization of these ring wave transients is found in ANSI/IEEE Standard C62.41-1991, "IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits." The IEEE standard ring wave has a rise time of 0.5 microseconds and oscillates at 100 kHz. The amplitudes of the standard ring waves range from 2,000 volts and 70 amperes to 6,000 volts and 500 amperes depending upon the location within the electrical distribution system. The higher amplitude transients occur closer to the electrical service entrance. The lower amplitude ones occur further inside the electrical distribution system. A pictorial representation of a standard IEEE ring wave transient is shown in Figure 2. below. Note that the rise time is 0.5 microseconds, the ringing or oscillatory frequency is 100,000 Hertz, and that the ring wave is damped or decays over time.

Figure 2. IEEE Standard Ring Wave Transient.
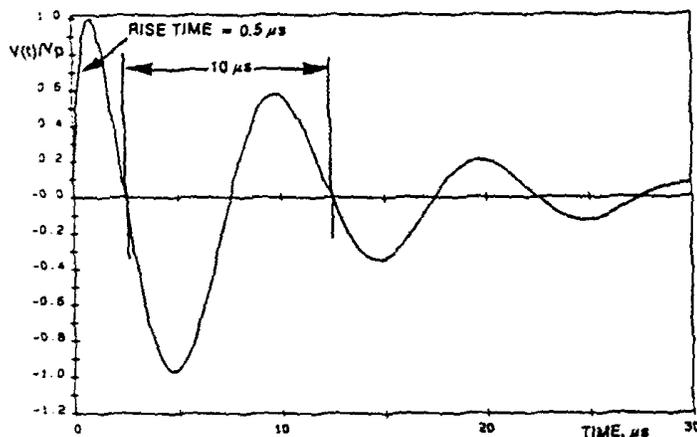
A pictorial representation of the suppression activity of sine wave tracking circuitry is provided in Figure 3. below. Note that the sine wave tracking circuitry is capable of addressing these voltage transients below the power frequency voltage peaks without interaction with the power frequency sine wave. The sine wave tracking circuitry produces an "envelope of protection" above and below the voltage sine wave as indicated by the dashed sine wave envelopes. The voltage transients of both positive and negative polarity are addressed within the "envelope of protection" as shown by the arrows which represent these transients.

Figure 3. Sine Wave Tracking Envelope of Protection and Ring Wave Suppression.
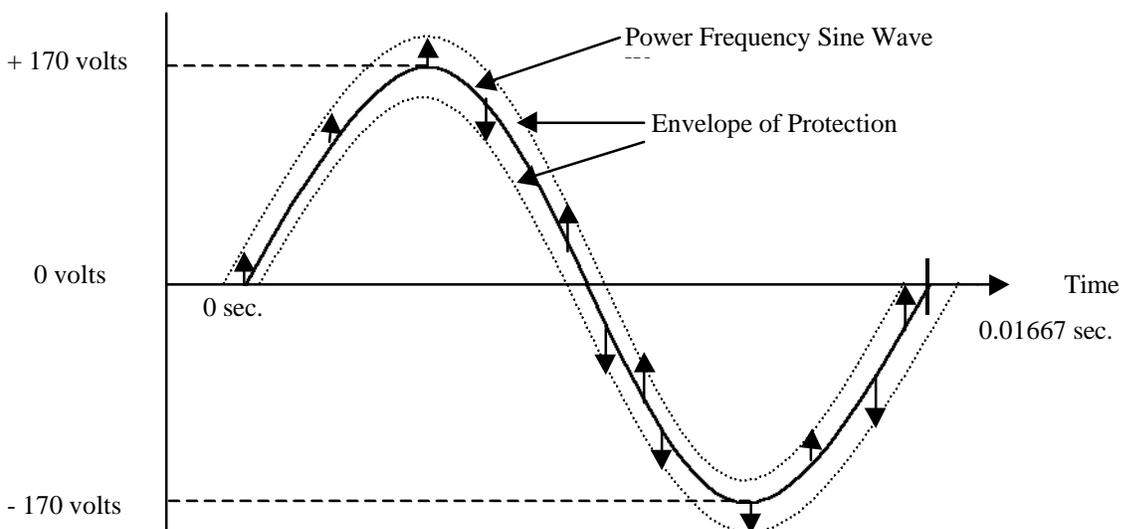

The sine wave tracking envelope of protection is symmetrical above and below the applied power frequency sine wave. The envelope of protection is seen to "track" the applied voltage sine wave; hence, it is called "sine wave tracking." A given ring wave transient will be suppressed at the same amplitude regardless of the polarity (positive or negative) or its phase angle with respect to voltage sine wave.

The ANSI/IEEE standard location categories per ANSI/IEEE C62.41-1991 are provided in Figure 4. below. These location categories are used to define the typical "exposure levels" for the various types and magnitudes of transients commonly experienced at typical facilities.

The magnitudes of the ring waves and there locations within a typical facility are provided in Figure 5. from ANSI/IEEE C62.41-1991. Note that these ring waves range from 2,000 volts at 70 amps to 6,000 volts and 500 amps.

Ring waves are real, they are defined by the IEEE, and they are most effectively deal with by employing a superior sine wave tracking surge suppressor. The let-through voltage of a surge suppressor, when hit with a ring wave, provides vital information concerning its ability to protect sensitive electronic systems.

Figure 4.
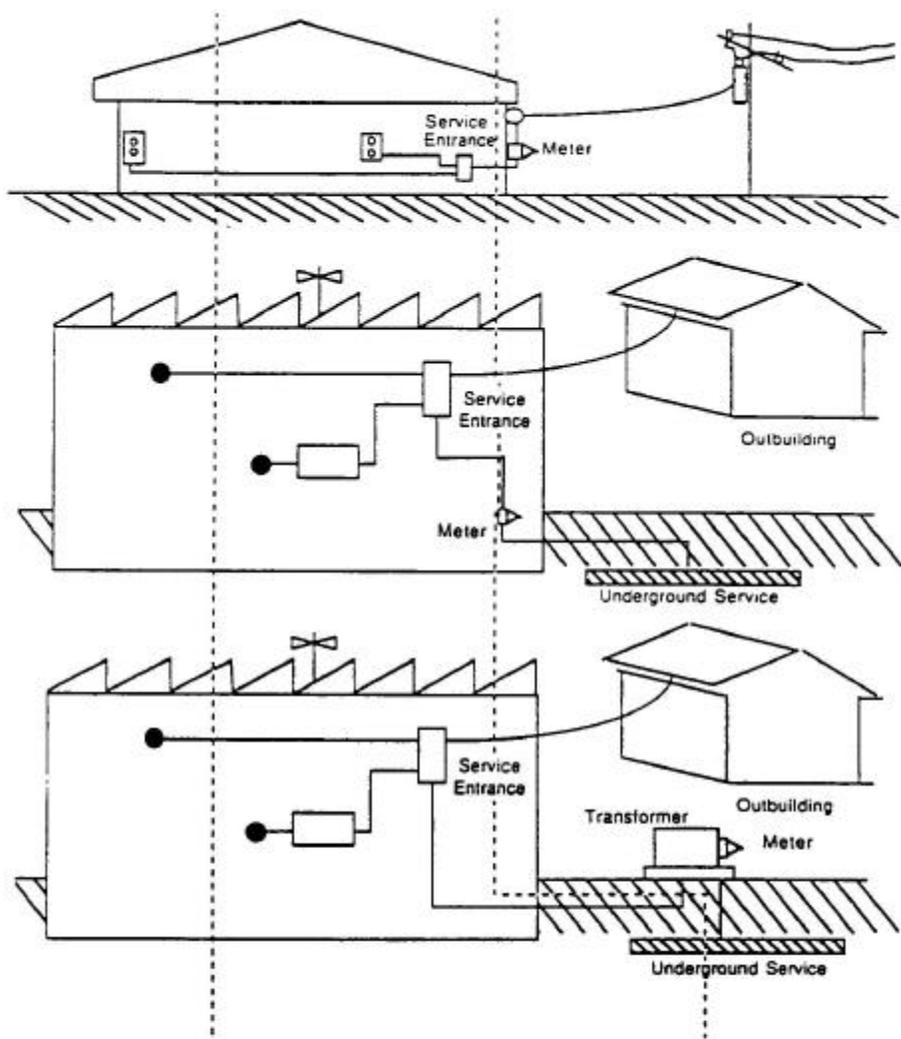
A	B	C
Outlets and long branch circuits	Feeders and short branch circuits	Outside and service entrance
All outlets at more than 10 m (30 ft) from Category B	Distribution panel devices	Service drop from pole to building
	Bus and feeder industrial plants	Run between meter and panel
All outlets at more than 20 m (60 ft) from Category C	Heavy appliance outlets with "short" connections to service entrance	Overhead line to detached building
	Lighting systems in large buildings	Underground line to well pump

Demarcation between Location Categories B and C is arbitrarily taken to be at the meter or at the mains disconnect (ANSI/NFPA 70-1990 [2], Article 230-70) for low-voltage service, or at the secondary of the service transformer if the service is provided to the user at a higher voltage.

Fig 9
Location Categories

Figure 5.

Table 3
Standard 0.5 μs–100 kHz Ring Wave

Voltages and Current Surges Expected in Location Categories* A and B[†]
Low, Medium, and High Exposures[‡]
Single-Phase Modes:[§] L-N, L-G, and [L&N]-G
Polyphase Modes: L-L, L-G, and [L's]-G
(See Table 5 for N-G Mode)

| Location Category* | System Exposure [‡] | Peak Values ** | | Effective Impedance (Ω)[††] |
		Voltage (kV)	Current (kA)	
A1	Low	2	0.07	30
A2	Medium	4	0.13	30
A3	High	6	0.2	30
B1	Low	2	0.17	12
B2	Medium	4	0.33	12
B3	High	6	0.5	12

* See 7.7 for definition and discussion of Location Categories.
[†] No provision is made for a 100 kHz Ring Wave in Category C.
[‡] See 7.3.3 for definition and discussion of system exposure.
[§] See IEEE C62.45-1987 [8] for discussion of coupling modes.
** The three values shown for each location category, for the three system exposures within the location category, have been set by consensus to provide guidance and uniformity in test procedures. Other levels may be negotiated between the parties involved.
In making simulation tests, use the voltage values shown for the open-circuit voltage of the test generator or the current values shown for the short-circuit current of the test generator (with coupling network and back filter in place).
[††] The effective impedance of the surge source, emulated by the test generator, is defined as the ratio of the peak voltage to the peak current. It has the dimension of a resistance, but is not a pure resistance (see 9.4.1).

Table 4
Standard 1.2/50 μs–8/20 μs Combination Wave

Voltages and Current Surges Expected in Location Categories* B and C[†]
Low, Medium, and High Exposures[‡]
Single-Phase Modes:[§] L-N, L-G, and [L&N]-G
Polyphase Modes: L-L, L-N, L-G, and [L's]-G
(See Table 5 for N-G Mode)

| Location Category* | System Exposure [‡] | Peak Values ** | | Effective Impedance (Ω)[††] |
		Voltage (kV)	Current (kA)	
B1	Low	2	1	2
B2	Medium	4	2	2
B3	High	6	3	2
C1	Low	6	3	2
C2	Medium	10	5	2
C3	High	20	10	2

* See 7.7 for definition and discussion of Location Categories.
[†] No provision is made for a Combination Wave in Category A; however, equipment connected to short branch circuits may be exposed to a moderate level of Combination Wave surges (UL 1449-1988 [B96]).
[‡] See 7.3.3 for definition and discussion of system exposure.
[§] See IEEE C62.45-1987 [8] for discussion of coupling modes.
** The three values shown for each location category, for the three system exposures within the location category, have been set by consensus to provide guidance and uniformity in test procedures. Other levels may be negotiated between the parties involved.
In making simulation tests, use the voltage values shown for the open-circuit voltage of the test generator or the current values shown for the short-circuit current of the test generator (with coupling network and back filter in place).
[††] The effective impedance of the surge source, emulated by the test generator, is defined as the ratio of the peak voltage to the peak current. It has the dimension of a resistance, but is not a pure resistance (see 9.4.2).

4. Are Sine Wave Tracking and EMI/RFI Filters the same thing?

While a number of surge suppressor manufacturers claim that an EMI/RFI filter is the same thing as sine wave tracking, the answer is no. As previously stated, EMI/RFI filter performance is measured in the frequency domain using the 50 ohm insertion loss method. A method not suitable for ac power distribution systems. The performance of sine wave tracking units is measured by applying standard ANSI/IEEE test ring wave transients and measuring the let-through voltage.